Linkage of South Florida Water Management Model and the Subregional Groundwater models of the Lower East Coast

Introduction

The evaluation of alternatives for the Lower East Coast 2020 Plan will require a linked application of the South Florida Water Management Model (SFWMM) and the subregional groundwater models. The regional model, SFWMM (Figure 1a), covers the entire lower east-coast region with 2 mile x 2 mile grid (mesh) and simulates the system-wide hydrologic implications of a selected alternative. The SFWMM simulates the groundwater system within its boundary using a vertically aggregated, single layer to mimic the composite effects of the non-homogeneous surficial aquifer. Conversely, the subregional models for the lower east coast (Figure 1b) use a stratigraphic three dimensional approach in which stratification in the surficial aquifer is simulated using multiple layers with intervening confining units that can transfer water from one layer to another. The groundwater models, developed using enhanced MODFLOW code typically consist of 500 ft. x 500 ft. spatial cells and up to 8 layers. Both the regional model and the subregional models typically have a stress period and a time step of 1 day. The use of these high-resolution groundwater models for a particular scenario requires information at their boundaries (including the surface), both in space and in time. This information can include, but is not limited to, water levels, discharges at structures located along the model boundary, recharge, evapotranspiration, and withdrawals from individual wells and wellfields. While most of this information can be generated independently for a particular scenario, others depend on the features of the regional system at large and therefore should be generated from the simulations of the regional system model (SFWMM).

(a) Regional System Model Boundary & Mesh

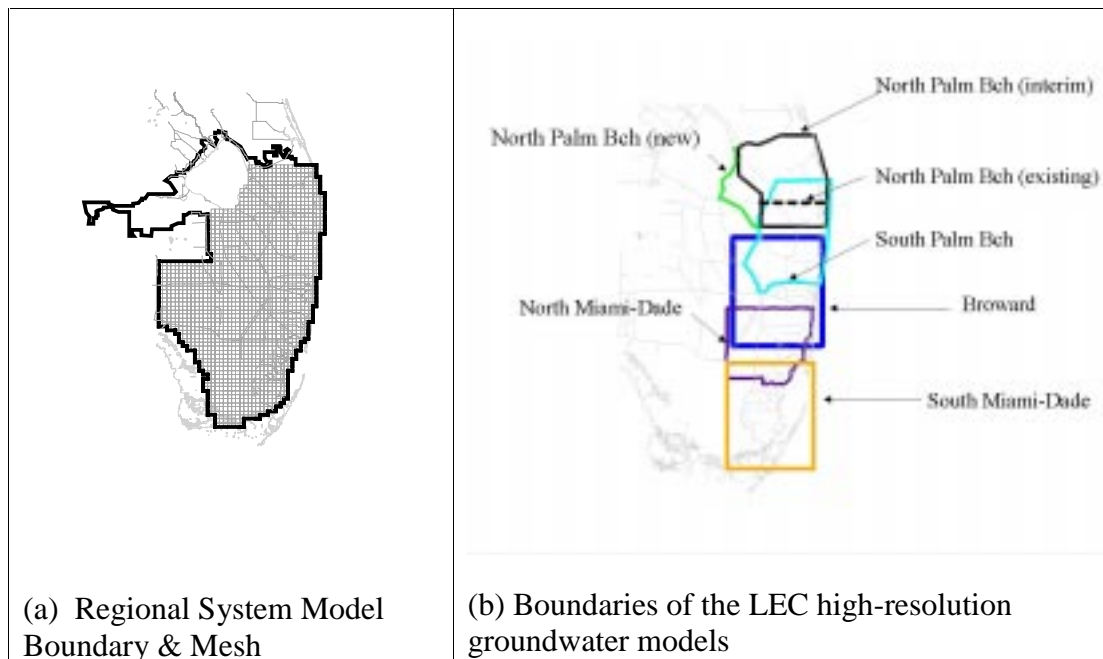(b) Boundaries of the LEC high-resolution groundwater models

Figure 1. Boundary and the 2 mile x 2 mile grid of the regional system model (left) and the approximate boundaries of the high-resolution, subregional groundwater models (right).

Typical Information Required for an LEC MODFLOW simulation
MODFLOW simulates groundwater flow in aquifer systems using the finite-difference method. The aquifer system is divided into rectangular blocks by a grid (Figure. 2). The grid of blocks is organized by rows, columns, and layers, and each block is commonly called a "cell."

For each cell within the volume of the aquifer system, the user must specify aquifer properties. Also, the user specifies information relating to wells, rivers, and other inflow and outflow features for cells corresponding to the location of the features. For example, if the interaction between a river and an aquifer system is simulated, then for each cell traversed by the river, input information includes layer, row, and column indices; river stage; and hydraulic properties of the river bed.

The MODFLOW model code consists of a main program and a series of independent subroutines called modules. The modules, in turn, have been grouped into "packages" which deal with a particular hydrologic process or solution algorithm. Typical packages being used for LEC simulations are shown in Table 1.
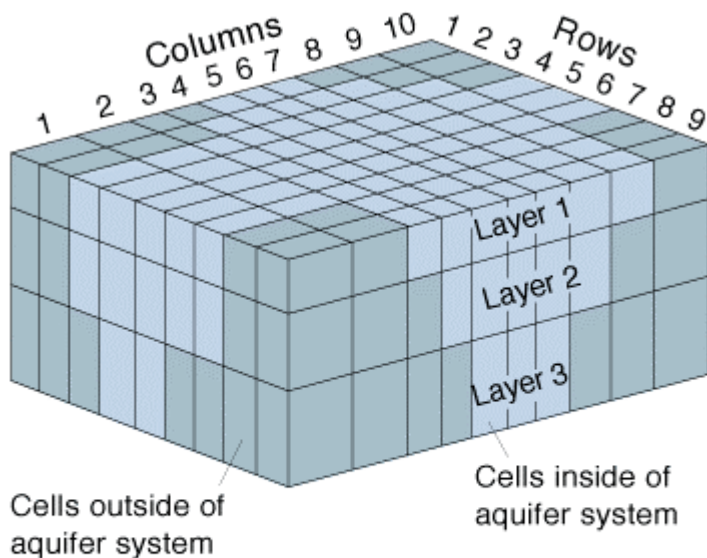

Figure 2. Example of model grid for simulating three-dimensional ground-water flow.

Linkage to SFWMM
Recharge and Evapotranspiration (ET):
For the planning applications of high-resolution groundwater models, recharge and ET time series are computed using an ET-Recharge model (Restrepo & Giddings, 1994).   This is an extension of the Agricultural Field-Scale Irrigation Requirements Simulation (AFSIRS) program (Smajstrla, 1990). The input rainfall for the AFSIRS model is obtained from the 2 mile x 2mile

cells of the rainfall input file of SFWMM. The potential ET for AFSIRS applications is computed using the Penman-Monteith formula for a reference crop of dense grass cover 12 inches in height. The meteorological data necessary for this approach are obtained from selected stations in south Florida.

Rivers and Drains:
The MODFLOW simulation periods (calibration or planning applications) are a subset of the simulation periods for SFWMM and therefore it is possible to extract water level data for the canals simulated by SFWMM for a particular scenario to be simulated by the MODFLOW model. The canals within the groundwater model domain have been classified (somewhat subjectively) as either rivers or drains depending on their particular purpose and configuration. Not all the canals in the primary and secondary drainage network in the Lower East Coast are simulated directly in the SFWMM although their hydrologic effects are accounted for in the regional model simulation. The groundwater models simulate most of the primary and secondary canal network. (See Figures 3 & 4 for examples). Using the water levels simulated by SFWMM for primary canals and other selected canals, the water levels for all the canals included in the groundwater models were estimated. This estimation accounts for the water surface slope in the canals as simulated in the SFWMM.
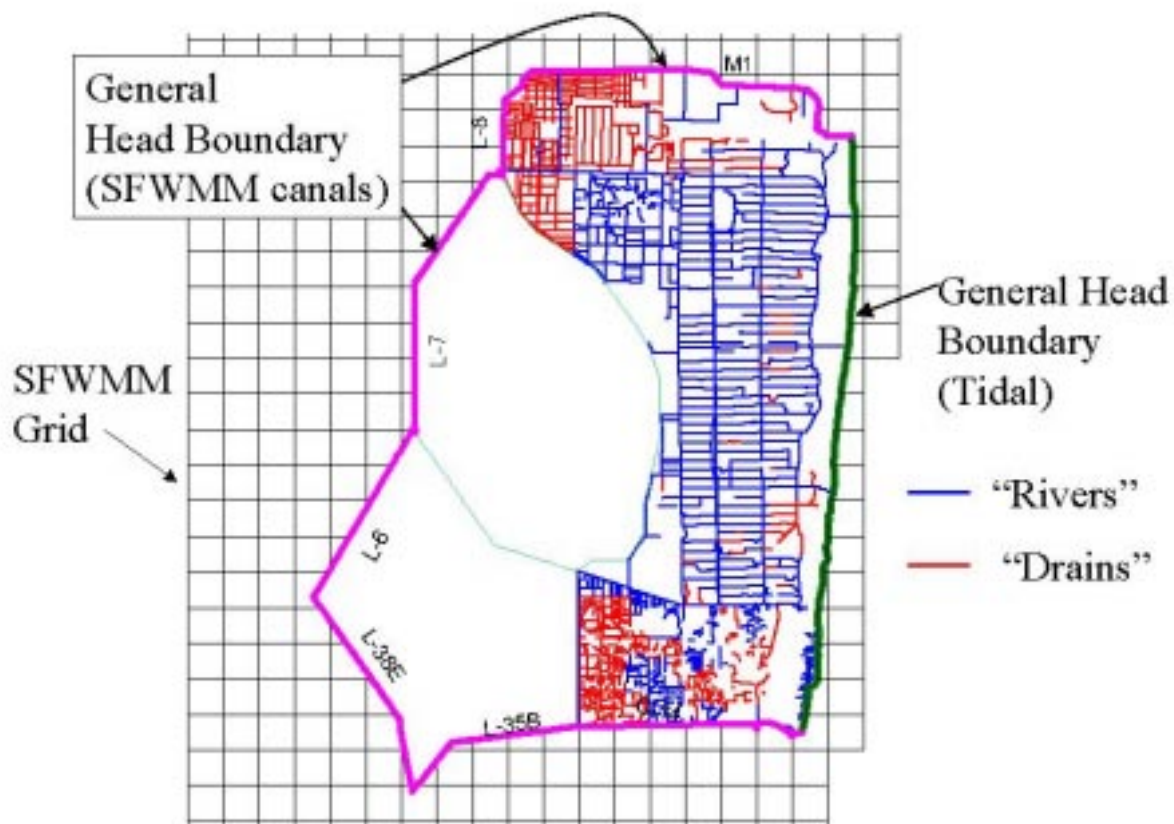

Figure 3. Illustration of canals classified as "rivers" and "drains" and the locations of general head boundary for the South Palm Beach groundwater model

Initial Heads:
Initial water levels (at the beginning of the simulation period) in all the cells of the groundwater
model are computed from the output of the SFWMM corresponding to that initial date
(12/31/87). For every 2 mile x 2 mile cell, there is over 400, 500 ft. x 500 ft. groundwater model
cells. First the water levels corresponding to the SFWMM cells are assigned to each of
groundwater model cells in that 2 mile x 2 mile cell. Next, the resulting high-resolution initial
water level grid is smoothed using the FOCALMEAN function of ARC/INFO. The same initial
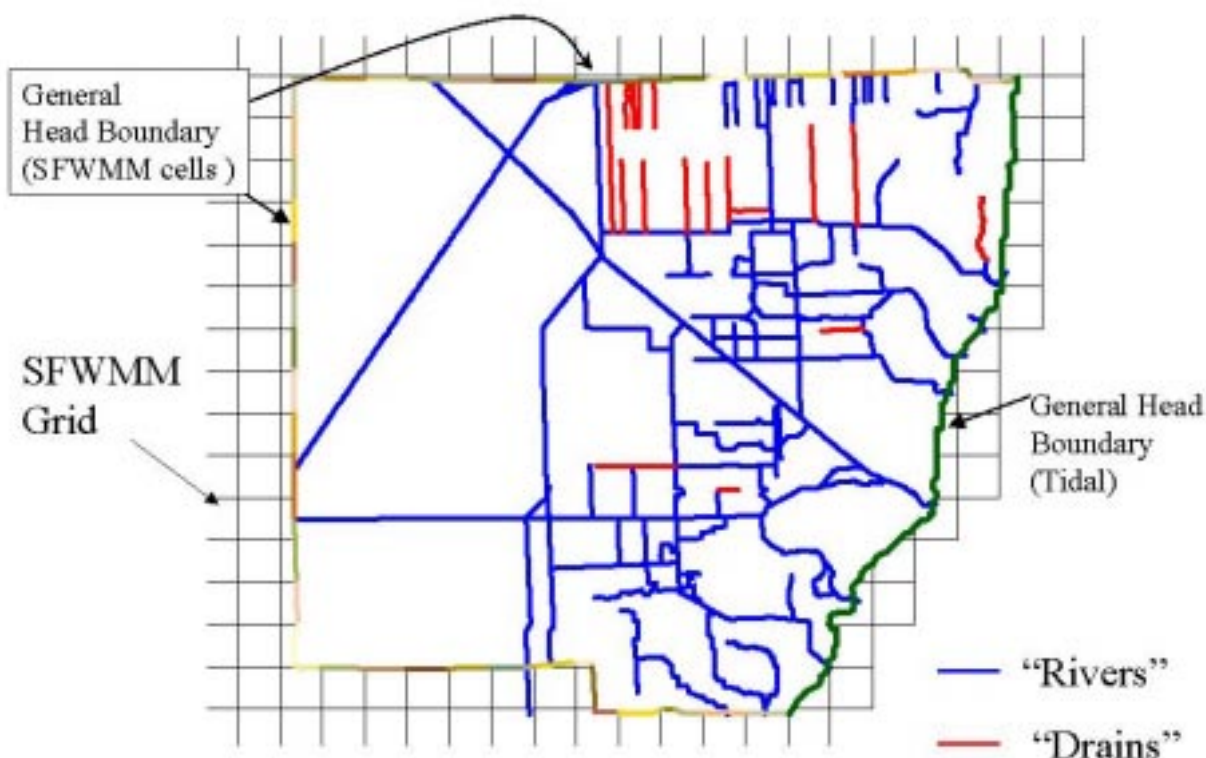head is assumed for cells in all
layers.

Figure 3. Illustration of canals classified as "rivers" and "drains" and the locations of general
head boundary for the North Miami-Dade groundwater model

General Head Boundary:
At all the cells located along the groundwater model boundary, water levels are needed to
simulate fluxes into and out of the model domain across Northern, Eastern, Southern and
Western faces (includes cells not only at the surface but cells of all layers) for all stress periods.
Generally, the eastern face (Figure 3 & 4) includes all the ocean cells and the water levels along
this boundary are computed from the nearest tidal station with measured data. A correction is
made to the computed head to account for density difference between the saltwater and
freshwater. The resulting ocean cell levels are termed "equivalent freshwater heads." In
addition, conductance associated with the general head boundary implementation is

progressively reduced (using a parabolic formula) to indirectly force the movement of freshwater towards the upper layers at the freshwater/salt water interface. This is an approximation for the complex three-dimensional nature of flow dynamics that typically occur near the interface.

The water levels from the remaining faces of the model boundary (generally northern, western, and southern) are estimated from the SFWMM for all stress periods. For example, the water levels in the groundwater model cells in the Water Conservation Areas are estimated from the corresponding water levels in the SFWMM simulation. Again, the same water level is assumed for boundary cells in all vertical layers. In some case, a primary canal simulated by the SFWMM corresponds to the groundwater model boundary. In this case, the canal water level from the SFWMM run is used to define the general head boundary.

Wetland Diversions:
Wetland module is used to simulate the overland flow in regional wetland systems within the model boundary. In certain cases such as in the South Palm Beach model, there are interior structures (e.g. S-10s) which divert water from one wetland to another (say from WCA-1 to WCA-2A). In such cases a diversion option in the wetland module is used to take water out from a group of cells in one area (say WCA-1) and spread over the receiving wetland (say WCA-2A). In order to improve the stability of the model computations, the group of cells selected for the diversion may be increased. As an example, the diversion regions for the Palm Beach model are shown in Figures 5. Water can also be "diverted" into the model domain from external sources. For example, discharges into the model domain across water control structures at the model boundary need to be simulated using the diversion option.
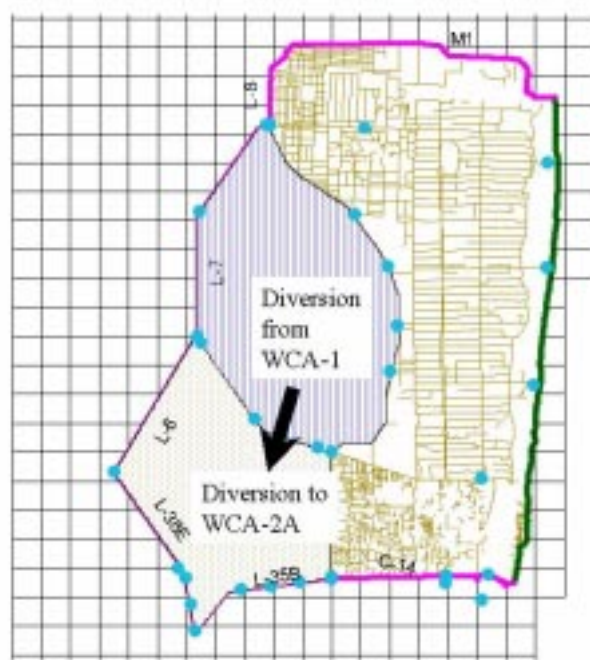

Figure 5. Illustration of the diversion regions in South Palm Beach model

Table 2. Typical MODFLOW "packages" used in LEC subregional models

Package	Description	Notes
Core		
Basic & Output Control	Specifies stress periods, starting heads, active model domain, # of layers, rows and columns, titles, units, output specifications etc.	Dry period: 88~89 Wet period:94~95 Simulation period for scenarios: 88~95
Block-Centered Flow	Steady State vs. transient, Row and column sizes, anisotropy, layer type, hydrogeologic data for each layer	Derived primarily from geologic data base used to construct the model
Stresses & Processes		
Recharge	Simulates areal distributed recharge to water table during each stress period	Pre-processed using SFWMM 2x2 cell rainfall and the AFSIRS based ET-Recharge model
Evapotranspiration	Simulates removal of water from the water table via transpiration and direct evaporation.	Same as above. Max ET rate diminishes with increasing water table depth
River	Simulates groundwater interchanges into or from canals classified as "rivers". Requires conductance, bottom elevation, and canal stage	Canal stages are usually extracted from SFWMM output. For canals not simulated by SFWMM stages are estimated using SFWMM stages at known locations.
Drain	Simulates smaller canals or other "drains" that remove water from the groundwater system. Requires drain control elevation and conductance. Canals classified as drains cannot supply water to the groundwater system	Stages are usually extracted from SFWMM. In some cases, permitted control elevations are used to simulate drains.
Well (multiple)	Simulates withdrawals from individual wells and wellfields for each stress period	Includes public water supply (PWS), irrigation, industrial, and ASR wells. Reflects current or projected allocations for each permit. Multiple wells enhancement provided by SFWMD allow PWS to be store separately from others.
Lake	Simulates interaction between the mining lakes (quarries) and the groundwater system	Lake configurations derived from land use coverage; Lake depths provided by mining industry. Module enhanced

Package	Description	Notes
		by SFWMD.
Wetland	Simulates the overland flow in wetlands using the uppermost model layer	Wetland vegetation coverage derived from land use coverage.
General Head Boundary	Simulates groundwater exchange between selected cells and a specified boundary as a function of water level difference.	Boundary stages are usually derived from SFWMM output (canal stages and/or stages in 2x2 cells)
Management		
Trigger Well	Simulates wellfield withdrawal cutbacks as a function of water level in "trigger wells" and Lake Okeechobee. Simulates LEC water shortage policy associated with saltwater intrusion.	Cutback zones are based on SFWMM, refined to include more details. Lake Okeechobee cutbacks based on the timing of such cutbacks simulated by SFWMM.
Horizontal Flow Barrier	Simulates artificial flow barriers underground (e.g. Sheet pile cutoff walls, slurry walls etc.)	Will simulate "curtain walls."
Seepage Return	Simulates backpumping from seepage collection channels by returning water collected in perimeter canals of the impoundment back into the impoundment.	
Solution Algorithms		
Strongly Implicit Procedure (SIP)	A mathematical solution algorithm internal to the model	Usually used.
Pre-Conditioned Conjugate Gradient (PCG)	A mathematical solution algorithm internal to the model. More computationally rigorous than SIP.	Used only occasionally when model experiences convergence problems.